Description of the 45,000-kv-a. Queenston Generators

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Review of the Subject.—*Notwithstanding the very large rated capacity of the 45,000-kv-a. generators for the Queenston power house of the Hydro-Electric Power Commission of Ontario, their essential construction features are not different from those of much smaller rated generators. The generators are of the vertical shaft type with two guide bearings, and a thrust bearing. The thrust bearing is located above the stator and carries the weight of the complete rotating elements of the generator and water turbine. Each generator is provided with a direct-connected exciter.*

The flywheel effect required for satisfactory speed regulation of the turbines necessitated the use of auxiliary flywheels mounted on the shaft adjacent to the generator rotor. The rotor is constructed with a number of cast steel wheels which together form the rotor spider for carrying the pole pieces. The pole pieces are made of punchings and are attached to the rotor with three dovetails per pole. The coils are made of copper strip wound on edge.

The stator frame is split vertically into three sections to conform with foundry and shipping limitations but the core is built up without being split. The stator windings consist of form-wound, diamond-shaped coils, each slot containing two coil sides. The coils are made of stranded conductor and are insulated with mica tape, which affords more or less flexible insulation. The ends of the coils are braced against the distorting effect of severe short circuits in such a manner as to permit expansion and contraction of the copper without injury to the mica insulation. The armature phase connections are made with bus rings supported from the stator frame, making all connections accessible.

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The purpose of this paper is to describe briefly a few of the construction features of the 45,000-kv-a. generators manufactured by the Canadian General Electric Company for the Queenston power house of the Hydro-Electric Power Commission of Ontario. Because of the fact that the rated capacity of these generators is greater than that of any generators ever before constructed, there is a tendency to create an impression that their construction would involve radical changes from the more or less familiar types of much smaller generators, but aside from one or two requirements peculiar to this installation, the problems presented in the design of these generators involved no great difficulties or departure from what has been considered standard construction. In fact if our power station engineers should find that larger generators could be used advantageously it is possible to build generators having capacities of 60,000 or 75,000 kv-a. at moderate speed without departing from ordinary methods of construction, or meeting with excessive costs per kv-a.

General Description

These generators are of the vertical shaft type with revolving fields and stationary armatures. They have two guide bearings and a thrust bearing. A substantial base ring supports the stator frame and carries the spider bracket for the lower guide bearing. The thrust bearing is supported by a deck or spider spanning the top of the stator frame and carries the rotating parts of the generator and turbine. There is a direct-connected exciter mounted at the top of the generator. A general view of the complete unit is shown in Fig. 1. The generators are designed to deliver three-phase, 25-cycle current at 12,000 volts, and rotate at a speed of 187½ revolutions per minute. The full-load rating is 45,000 kv-a. at 80 per cent power factor, with a temperature rise not exceeding 65 deg. cent. as observed by detectors imbedded in the slots of the stator core or by resistance measurements of the

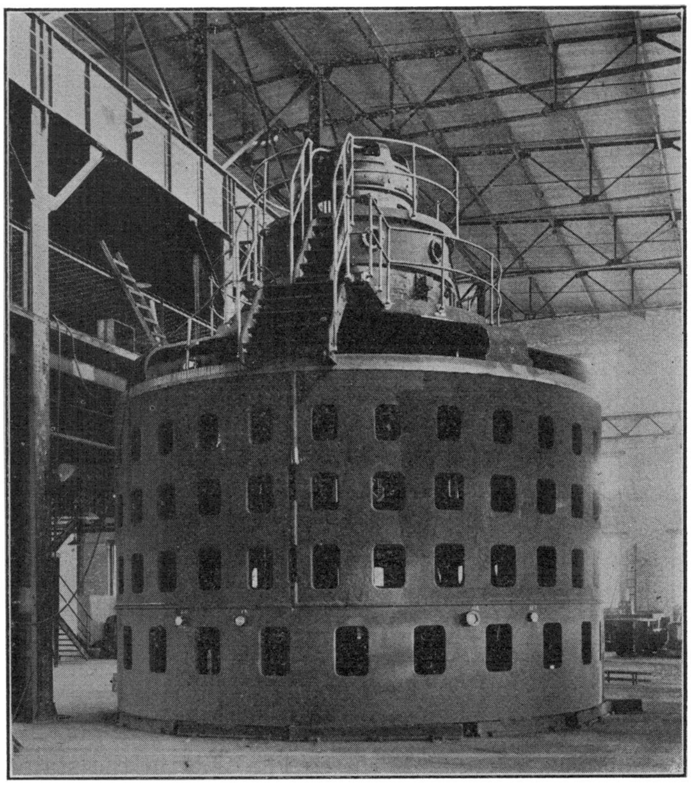

Fig. 1—General View of the Assembled Unit

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stator or rotor windings. The full-load efficiency including all mechanical and electrical losses is guaranteed to be not less than 97¾ per cent at 100 per cent power factor. The exciters are rated 150 kw. at 250 volts.

STATOR FRAME, CORE AND WINDINGS

The stator frame is divided into three sections vertically, in order to keep the weight within the foundry capacity and provide sections of a size and weight that could be easily handled in the shop and in transportation. These castings are probably the largest in size and weight ever used for generator construction, the frame being 24½ ft. in diameter by 10 ft high, and weighing, complete, approximately 90 tons. In building the core of such a large generator it is desirable to avoid joints that divide the core into sections because looseness and vibration of the laminations are liable to develop due to the unequal expansion of the frame and core, and the difficulty in arranging clamps capable of exerting sufficient pressure. Therefore it was decided to build up the core in the power station thus obtaining a continuous ring. The slots in the stator core are unusually large for a waterwheel type generator, being as large as those commonly used in the large high-voltage turbo-generators. The stator winding is of the common "Barrel" type with two coil sides per slot. Each turn of the coils is insulated with mica tape applied by hand after the coil has been formed. The coil insulation consists of mica tape put on by hand with a special compound sticker between layers. This process results in a uniform insulation on the full length of the coil and when slightly heated a sufficient flexibility is obtained to permit the removal and assembly of coils without great danger of damage to the insulation. The semi-plastic condition of the insulation also permits the expansion and contraction of the copper, due to changes in temperature, with a minimum disintegrating effect on the mica in the insulation.

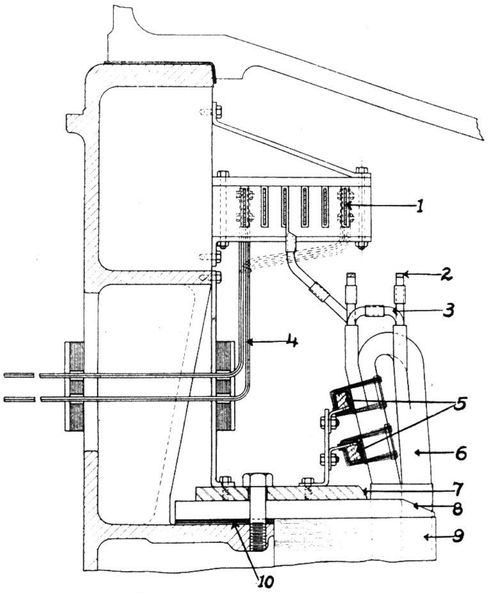

FIG. 2—ARRANGEMENT OF STATOR COIL CONNECTIONS AND COIL BRACING RINGS

1. Phase bus rings.
2. Pole connections.
3. Group connections.
4. Terminal leads.
5. Bracing rings.
6. Stator coil.
7. Clamping flange of core.
8. Clamping fingers.
9. Punchings or core.
10. Removable shims to allow taking up settling of core.

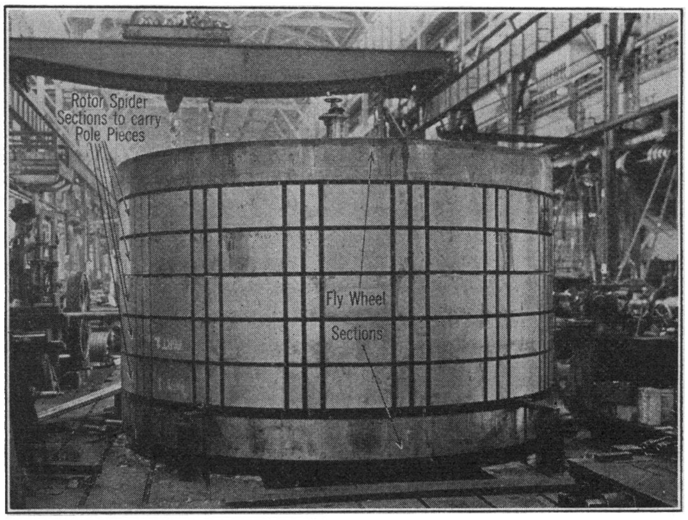

FIG. 3—THE ROTOR

STATOR COIL SUPPORTS

The projecting ends of the coils at both the top and bottom are braced against one another by small wooden spacers, placed between the sides of the coils, and the whole winding is supported at each end, against the distorting effect of short circuits by two complete steel rings which are supported from the frame by suitable iron brackets. The windings are bound securely to the supporting rings with treated cord. This method of binding permits of a certain amount of flexibility that is desirable to allow for the expansion and contraction of the coils due to changes in temperature. The bracing rings are covered with insulating material not only for insulating purposes but to act as a cushion for the coils to rest against, and to take the sharp blows resulting from severe short circuits without cutting the coil insulation.

POTENTIAL WAVE

The stator coils are chorded to take advantage of fractional pitch properties in obtaining a voltage wave form as near as possible to the ideal sine wave, and to eliminate the objectionable harmonics.

ARMATURE CONDUCTOR

The section of copper necessary to carry the current in the stator windings being too large to use a single strand, the conductor was subdivided into a number of strands of small section to facilitate the forming of the conductor in the coils and also to reduce largely the eddy current losses in the copper. The phase connections of the stator winding have been taken care of in a rather unusual manner by the use of a bus ring arrangement supported from the inside of the stator frame. The connections between these bus rings and the windings are made with flexible connections which can be disconnected. This arrangement allows free access to all the connections for cleaning and inspection, and permits the removal of damaged coils without disturbing the connections.

VENTILATION

Air for cooling the generator is admitted to the pit beneath it, through ducts from outside the station, or from the generator room, and is drawn into the machine by the blower action of the rotor. The air is expelled through the openings in the stator frame into a chamber surrounding the generator, and is then exhausted by a fan through a ventilating shaft through the roof, or to the different parts of the power house as desired. Because of the large volume of air required (about 120,000 cu. ft. per minute) it was necessary to give special consideration to the ventilation in the construction of the generator and power house. The unique provisions in the design of the power house for the generator ventilation are described in another paper being presented at this meeting.

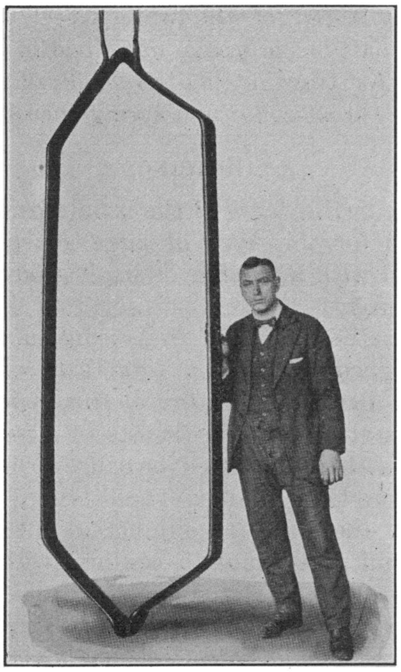

Fig. 4—Stator Coil

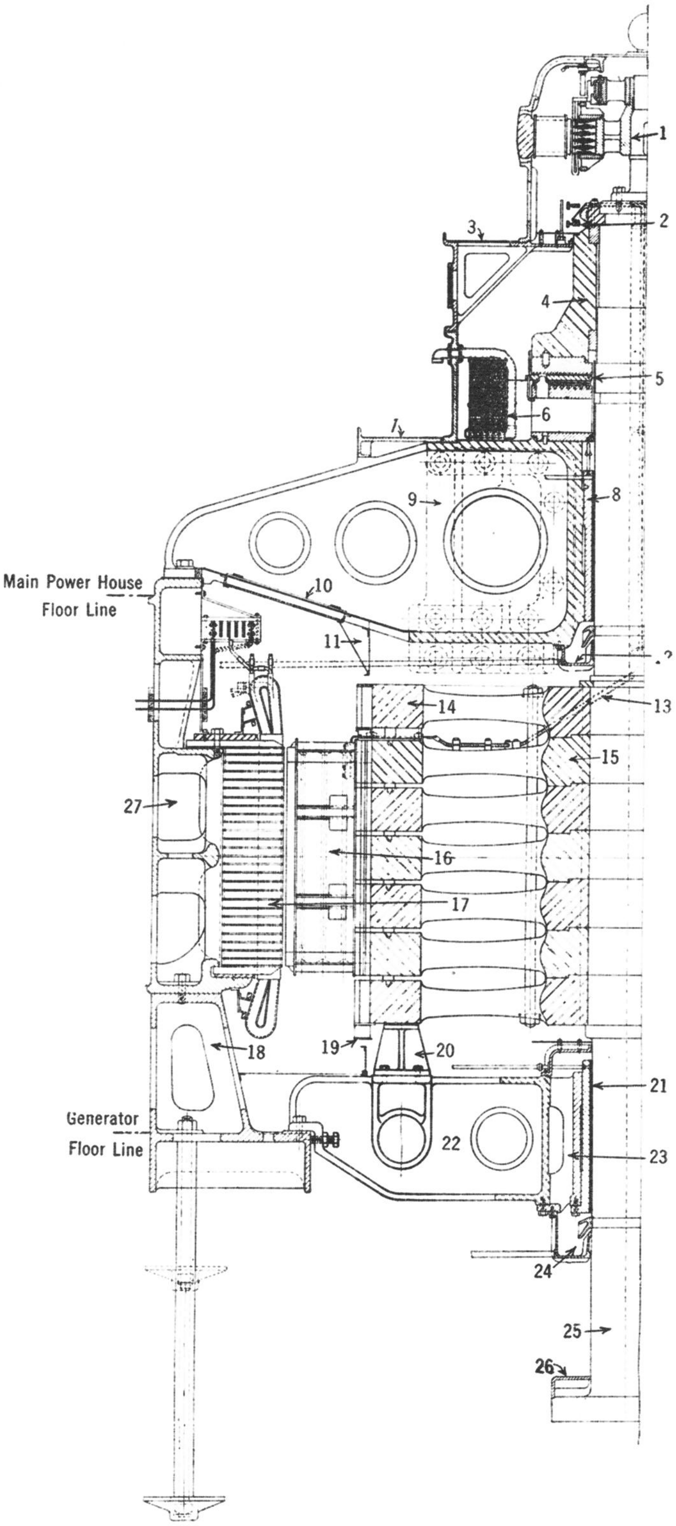

Fig. 5—Complete Assembly Sectio it

1. Exciter.
2. Collector rings.
3. Exciter platform.
4. Thrust collar.
5. Spring thrust bearing.
6. Water cooling coils.
7. Thrust bearing platform.
8. Upper guide bearing.
9. Upper bearing bracket
10. Cover plate and manhole.
11. Air baffle ring.
12. Upper oil drip pan.
13. Collector leads.
14. Flywheel section.
15. Rotor spider section.
16. Pole piece.
17. Stator core.
18. Base ring.
19. Fans.
20. Pedestal for supporting rotor.
21. Lower guide bearing.
22. Lower bearing bracket.
23. Lower guide bearing housing.
24. Lower oil drip pan.
25. Shaft.
26. Coupling bolt guard.
27. Stator frame.

FLYWHEEL EFFECT

To meet the requirements of the hydraulic equipment in regard to speed regulation under conditions of sudden changes in load, the rotor was required to have a much larger flywheel effect than would have been obtained if the rotor were designed with reference only to the strength required. A limited amount of this flywheel effect was available in the pole pieces with their coils, and the balance had to be obtained principally in the rim of the rotor spider. It was found that if the axial length of the rotor spider rim were limited to the length of the pole pieces the radial thickness of the rim would be so great that the air passages between the rim and the hub would be restricted too much to allow sufficient air to reach the upper ends of the rotor and stator coils. Therefore the unusual arrangement was adopted of providing two independent spiders or flywheels mounted on the shaft, one at each end of the rotor spider proper. These flywheels are of the same diameter as the rotor spider in order to allow for the assembly of the pole pieces. The rotor spider is sectionalized into five wheels so that the complete rotor with the flywheels consists of seven separate wheels which are mounted on the shaft, one above the other. The hubs of these wheels are slightly wider than the rims so that openings are left between the rims to allow air to pass through to the spaces between the pole pieces. The ventilation is further assisted by curved fan blades attached to each end of the rotor and the recirculation of the air is prevented by baffle plates and covers around the ends of the stator windings.

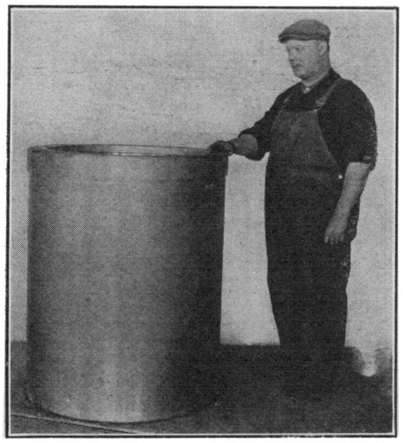

FIG. 6—UPPER GUIDE BEARING

FIELD COILS

The field coils are probably the largest ever made. Each coil is wound from a continuous strip of copper 1100 feet in length and weighing 2600 pounds. This strip is wound on edge in the usual manner and the adjacent turns are insulated from each other with asbestos and mica. The insulation between the coil and the pole core is of mica sheets while the insulating collars are of asbestos board so that the coils can be subjected to considerable heat without injury. This fire-proof insulation was not thought necessary because of an excessive temperature rise in normal service, but to prevent injury to the coils by a fire in the generator resulting from a failure in the stator winding.

POLES

The pole pieces are of the usual construction having 1/8-inch punchings riveted together between heavy cast steel end plates. Each pole has three parallel *T*-shaped dovetails which are designed to withstand the stresses due to double normal speed, without exceeding half the elastic limit of the material. Each pole with its coil weighs five tons and the peripheral velocity of the pole face at normal speed is over two miles per minute. The flywheel effect of the complete rotor is equivalent to 21,000,000 pounds at one foot radius. The shaft which is 30 inches in diameter in the bearings, has a solid forged coupling. In order to insure ample stiffness of the shaft, the critical speed with the rotor and shaft in a horizontal position was kept well above the run-way speed of the water-wheel. The upper end of the shaft has a groove machined in it to receive a split ring for transmitting the weight of the rotating parts to the thrust collar and spring thrust bearing.

BEARINGS

The guide bearings are of the usual General Electric construction for this type of large generator. They are provided with a number of small grooves for lubricating purposes.

The thrust bearing is of the spring supported type and is designed to carry a total load of 500 tons. Briefly, the distinctive feature of this type of bearing is that the stationary part consists of a relatively thin steel plate with a babbitted bearing surface which is supported by a large number of coil springs. The slight flexibility of the plate in conjunction with the spring support permits the plate to conform with any slight irregularity either in the supporting structure or the shaft and thrust collar without causing local unit pressures large enough to prevent the maintenance of a film of oil between the bearing surfaces. The thrust bearing operates in a bath of oil which is renewed at a comparatively low rate with clean oil from the station oil system. The heat generated in the bearing is taken up directly by the oil as it passes through and around the bearing plates and is then removed from the oil by water cooling coils immersed in the oil bath.

BEARING BRACKETS

The upper bearing bracket or bridge-tree for supporting the thrust bearing and exciter, has eight arms and is of cast steel. Because of shipping limitations it is split into halves which are joined together with fitted bolts. The complete bracket was tested at the factory with a load of 1000 tons by means of hydraulic jacks. This test load is double the normal operating load and gave assurance that the castings were sound. Cast steel was used for these brackets not only because of its greater strength but also to limit the deflection to a value that would not interfere with the adjustment of the bearings or other parts of the generator and turbine. The calculated deflection of 47 mils was reasonably consistent with the observed value of 35 mils. The castings were slightly thicker than the drawing dimensions which fact probably accounts for the difference between the two values.

The openings between the arms are closed with sheet steel covers. Manholes of generous dimensions in these covers permit ready access to the upper part of the rotor and stator for cleaning and inspection.

In view of the fact that this power development is public enterprise and therefore will be open to public inspection, much attention has been paid to the design of the thrust bearing bracket, exciter and platforms, and railing, to obtain graceful proportions, and at the same time present an impression of strength and massiveness in keeping with the great power capacity of the generator and station. Two platforms are provided the lower one for inspection of the thrust bearing and the upper one for the inspection of the exciter and collector rings. The exciter armature is mounted on a short shaft with a forged coupling which is bolted to the top of the generator shaft. The collector rings are mounted on the generator shaft just below the exciter coupling and in case the exciter armature is removed for repairs it is not necessary to disturb the generator collector rings and the generator can be kept in service while the exciter armature is being repaired.

The lower guide bearing bracket is supported on the inner projection of the base ring. The opening for the guide bearing is large enough to pass the coupling on the shaft. The guide bearing shell is made as light as is consistent with good construction to facilitate removal, and is supported in the bearing bracket by the housing. Both the shell and housing are assembled and removed from below the bracket. The arms of this bracket have pads directly beneath the rim of the rotor spider, four of which are for the air brakes. The other four are to be used for lifting jacks for raising and supporting the rotor when assembling and dismantling the thrust bearing. The arms are designed so that four of them have ample strength to support the weight of the rotating parts of the generator and waterwheel.

DIMENSIONS AND WEIGHTS

In conclusion the following weights and dimensions may assist in formulating a conception of the size and proportions of these generators:

Outside diameter of stator frame	24 ft. 6 in.
Over-all height from face of coupling to top of exciter	33 ft. 10 in.
Over-all height from base ring	28 ft. 3 in.
Weight of stator with core and windings	175 tons
“ “ base ring	37 “
Diameter of shaft in rotor	32 inches
“ “ coupling	53 “
Length of shaft	30 feet
Weight of shaft	40 tons
Weight of upper bearing bracket	50 “
“ “ lower “ “	12 “
Diameter of thrust bearing	69 inches
Load on thrust bearing	500 tons
Weight of one pole piece with coil	5 “
“ “ rotor spider (7 sections)	190 “
Total weight of rotor	310 “
“ “ “ generator with exciter	625 “

65 miles of wire used in one set of stator coils.

450 miles of tape used to insulate one set of stator coils.

110,000 punchings required for stator core.

3½ miles of copper strip used for one set of pole coils.

4 tons of cooling air required per minute.

Discussion

For discussion on this paper see p. 507.